Advances in River Sediment Research – Fukuoka et al. (eds)
© 2013 Taylor & Francis Group, London, ISBN 978-1-138-00062-9

User guide to gravelometric image analysis by BASEGRAIN

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ABSTRACT: BASEGRAIN is a MATLAB-based automatic object detection software tool for granulometric analysis of top-view photographs of fluvial non-cohesive gravel beds. It is handled via a graphical user interface, which enables post- and pre-processing as well. The core of the software code is a sophisticated five step object detection algorithm that separates interstices from grain areas. A quasi grain size distribution is derived from the *b*-axes of the detected grain top view area following a line-sampling methodology. Results are exported to common spreadsheet-file and GIS-file formats. If geotagged photographs are analyzed, georeferencing is done automatically. BASEGRAIN is freely distributed over the Internet in binary form, but the source code remains closed. The present paper contains background information on the object detection methodology used and focuses on how to apply BASEGRAIN in the most efficient way.

1 INTRODUCTION

Information regarding the composition of a river bed is crucial when dealing with fluvial processes. Especially the knowledge of the grain size distribution is important for several aspects, e.g. to obtain roughness estimates for modeling hydraulics, to perform sediment transport calculations, to classify aquatic habitats, and to evaluate geological deposits, respectively.

Classical laboratory sieving requires a demanding effort on technique and personnel to classify sediments, while the whole process of digging, transport and sieving is time-consuming and cost-intensive. Alternatively, numerous in-situ methods were developed to gain grading curves especially for coarser sediment, e.g. based on inventorying single grains by means of a grid (Wolman, 1954) or along a line (Fehr, 1987). Yet these methods are time-consuming as well as prone to be imprecise in accuracy. Furthermore they are hardly to apply for a completely wetted bed.

In recent years several automatic approaches have been developed to analyze areal bed information from digital recordings. A separation in two groups can be made as follows:

A first group focusses on achieving only one single characteristic ('bulk') grain size parameter. Successful procedures originate from Carbonneau et al. (2004, texture analysis of air-borne photographs), Heritage and Milan (2009, texture analysis of terrestrial laser-scanning), or Buscombe et al. (2010, frequency analysis of digital micro-photographs).

Beyond this, a second group uses image processing techniques to detect and to measure each grain area and its related properties via digital top-view photographs. These sophisticated methods allow for classifying the grain sizes at the uppermost layer of a gravel bed. Furthermore an opportunity is given to estimate the grain size distribution of the subsurface material as well. Successful procedures originate from Weichert et al. (2004, simple grayscale threshold approach), Graham et al. (2005a, combined approach with a grayscale threshold and bottom-hat filtering, followed by a watershed algorithm) and Strom et al. (2010, method similar to Graham's approach). Graham et al. (2005b) showed that the small axis of an ellipse fits to detected grain areas, i.e. the apparent *b*-axis gives an adequate proxy to the related characteristic diameter, measured via laboratory sieving. In 2005, Graham and co-workers published the fee-required software Digital Gravelometer to measure gravel sediments. It comprises image processing and analysis reporting. However, no further development of the software was carried out and no update was released.

Inspired by Digital Gravelometer, Detert & Weitbrecht (2012) developed an optimized object detection methodology. Its implementation was published as free software named BASEGRAIN and improves comparable tools in several aspects: (1) Within the preprocessing, crude image filters are omitted to preserve detailed information about possible interstices; (2) The detection of interstices is expanded to the application of edge detection filters; (3) The watershed algorithm is improved significantly to avoid over-segmentation; (4) Single grain elements can be handled within a post-processing by a Graphical User Interface (GUI);

(5) Fehr's (1987) prognosis approach to estimate and close the subsurface layer lack is implemented; and (6) If geo-tagged photographs are analyzed, georeferencing is done automatically.

Below the software tool BASEGRAIN is presented in detail. After a short resume of the implemented methodology the focus of the present article deals with the application of the GUI.

2 METHODOLOGY

The core of the software code BASEGRAIN is an object detection algorithm automatically separating interstices from grain areas of digital top-view photographs. The methodology involves MATLAB-based object detection techniques applied to analyze gravel layer surfaces.

The methodology is based on five detection steps. The first aim is to get a precise detection of the interstices. Once all interstice pixels are known, the grain pixels, i.e. all non-interstice pixels, are detected as well. The methodology is described in Detert & Weitbrecht (2012). A short summary of the five steps are given below.

Within step #1 interstices are detected using a double grayscale threshold approach. The first greythresh level initially determines definite interstices. Typically this level is selected best at 50% of the threshold value, as defined by the method of Otsu (1979). The second grey-thresh level gives an estimation to possible interstices. Typically this level is chosen best at 40% above the first greythresh level. The resulting possible interstices are confirmed if they are connected to the definite interstices as found by the first grey-thresh level.

Step #2 performs morphological bottom-hat filtering on the grayscale image to get access to further possible interstices. Possible interstice areas in the bottom-hat filtered image typically are confirmed if they are connected by ≥5% to the definite interstices from step #1.

During step #3 two gradient filter techniques are applied, i.e. the Sobel method (MATLAB, 2012) to detect strong edges, as well as the method of Canny (1986) to detect weak edges, respectively. Canny edges are confirmed if ≥25% of their area is congruent to previously confirmed interstices. Sobel edges are used to confirm further Canny edges in the same way and based on the same criteria. At the end of step #3 the confirmed interstices are smoothed by morphological operations.

At step #4 the focus of the analysis changes from the detection of interstice areas to the separation of single grain areas. A watershed algorithm is applied twice. First, watershed bridges are identified from the inverted binary outcome matrix from step #4 and get dilated by a disk-shaped element of radius 4 px. Areas of Canny edges are confirmed by these watershed bridges if they get completely masked and if their interrelated orientation angle differs by <10°. Second, watershed bridges are identified from the actual binary outcome matrix. Bridges are confirmed if their area is smaller than a threshold of typically 40 px to suppress over-segmentation.

Step #5 is needed for final operations. The goal is to obtain the region properties of each grains top-view area. Ellipses are fitted to object areas using normalized second central moments of determined object areas. Their minor axes, i.e. the *b*-axes, are taken as proxies of characteristic grain diameters. Boundary grains that are not fully included within the analyzed frame are blanked out to avoid a misleading statistical analysis of the characteristic diameters.

3 BEST PRACTICE GUIDES TO TAKE PHOTOS

When photographing a gravel bed, several factors have to be considered influencing the quality of the automatic object detection results. For typical applications in fluvial engineering a hand held camera of commercial quality with at least >2 Mpx is needed. Even nowadays smartphone cameras deliver photos of satisfactory quality—and offer the possibility to take GPS-tagged pictures. The camera should be positioned perpendicular to the bed to avoid perspective distortion and the related bias, as only one single scaling factor is used for the whole image. However, optical distortion showed to be of minor importance to the resulting accuracy. The minimal distance between camera and bed is defined by the smallest grains that should be resolved on the photo. A rule of thumb can be derived from Graham et al. (2005b), stating that the smallest detectable grain area comprises 23 px.

In case of sunny weather cast shadowing should be minimized by using parasols or similar sunshade measures to suppress over-segmentation in the detection process. Optimally, the weather is cloudy to get diffuse light conditions.

Wetted stones in general lead to increased intensity of the intra-granular color texture. This phenomenon promotes over-segmentation as well. Especially locations with partly wetted stones should be avoided, as the detection algorithm tends to separate these stones into several parts. If wetted stones have to be accepted on the photograph, flash light should be switched off to avoid reflection hot spots in the image.

If possible, disturbing 'non-grains' like for instance grass, leaves, mussels, snow, or the photographers shoes should be avoided to appear on the photograph.

A differentiation between grain interstices and intra-granular textures as well as breaking edges on stones is in general challenging to handle by the detection methodology. However, a distinction can be handled manually within the implemented post-processing options. A high percentage of cohesive or fine material that is not resolvable extends the analysis time, as the related areas have to be blanked out manually within the post-processing.

4 BASEGRAIN

4.1 *Software*

BASEGRAIN belongs to the growing family of BASEMENT, the software package of VAW (ETH Zurich) for hydro-numerical modeling of fluvial aspects in 1D and 2D that optionally includes sediment transport as well. BASEGRAIN is freely distributed over the internet in binary form, yet the source code remains closed. This software is available at www.basement.ethz.ch/services/Tools/basegrain. The current version of BASEGRAIN requires a 64 bit version of Windows 7.

4.2 *Installation*

The software BASEGRAIN needs MATLAB Compiler Runtime (MCR) to be installed first—while BASEGRAIN itself can be run without any extra installation. A download link to MCR is given on the BASEGRAIN homepage (see §4.1). MCR can be downloaded for free as well. Note that administrator rights are needed to install MCR.

4.3 *Data import*

After starting BASEGRAIN the user has to be patient for at least 60 s, as the MCR has to be launched in the background. Optionally, all running processes on the computer can be checked via the task manager of the system software.

The data import menu is started by pressing the blue 'load data' button (shortcut key 'l'). An initial control parameter file has to be imported or, alternatively, the default settings can be used. The control parameter file contains the information needed to steer the forthcoming analysis process and includes as well the name and path of the image that is to analyze. The parameter file is a simple ASCII text file written in MATLAB-editor language, called m-file. This file can be opened and changed by the user via common text file editors without the necessity of a full MATLAB installation.

Optionally, the user has the possibility to change the image file that should be analyzed. Furthermore the image size can be downsized by changing the parameter 'resizI' to <1.0 to decrease the time needed for automatic object detection. However, downsizing normally diminishes the precision of the automatic analysis results as the minimal detectable grain size is decreased in this way as well. If the image scale in [mm/px] is known, the user can type in the value in the related text field. Otherwise, the image scale is determined interactively via the interactive scaling device (see §4.4).

The actual settings of the data import menu are saved by pressing the 'ok' button.

4.4 *Inspection tools*

Once the data import is finished the full image to be analyzed appears on the working surface of the main menu. Figure 1 shows a typical screenshot at this state of analysis. The photo can be inspected via the inspection tools menu that comprises four buttons as described next.

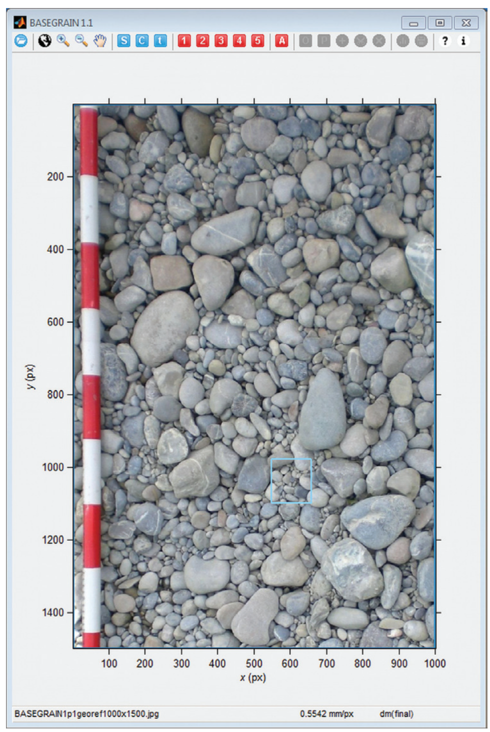

Figure 1. Screenshot of BASEGRAIN working surface, with toolbar, information bar at baseline and top view photograph of gravel bed to be analyzed. Larger rectangle (color print: blue) defines area to be analyzed, and small rectangle (color print: light blue) encloses area where analysis parameter can be tested against their influence on object detection performance (§4.5).

The ‘GeoReference’ button is only active if the actual photo is geo-tagged on its Exif-data. By pressing this button the default web browser is launched and directly linked to http://toolserver.org/~geohack, where the actual geographical coordinates of the photo can be checked via global and local map services.

The three buttons ‘zoom-in’, ‘zoom-out’ and ‘pan’ give a handle to navigate on the photo. Note that they have to be switched off by a second click on the last used button afterwards not to get in conflict with the preprocessing and post-processing buttons.

4.5 *Preprocessing*

Preprocessing involves scaling and image cropping. The interactive scaling device is activated by pressing the blue ‘scale’ button (shortcut key ‘s’). A measuring tool pops up on the working surface. Its ends can be moved by the mouse to known distance points on the photo, e.g. a folding rule or a leveling rod. The known distance in [mm] has to be typed in the request field. Both the ‘check’ button and afterwards the ‘ok’ button have to be pressed to successfully scale the image. Now, the baseline of the working menu shows the scaling factor in [mm/px].

The area to be analyzed later on can be cropped by the mouse after clicking the blue ‘crop section’ button (shortcut key ‘c’). The first left mouse click draws up a rectangle. The selected area is fixed by a final double left mouse click and gets highlighted and blue-framed afterwards.

In a similar manner an area can be set out where parameter combinations can be tested for their efficiency on each of the five steps within the object detection methodology. Cropping is started by clicking the blue ‘test crop section’ button (shortcut key ‘t’). The first left mouse click draws up a rectangle. The selected area is fixed by a final double left mouse click and gets highlighted and blue-framed afterwards.

If no preprocessing is done, BASEGRAIN applies default values during the forthcoming jobs.

4.6 *Parameter adjustment*

Each of the five steps of the object detection methodology is controlled by a certain parameter set. Access to change their default values is given via the respective buttons ‘1’ to ‘5’ (shortcut keys alike). A new window pops up, where each single parameter can be changed. Effects on the test area result by pressing the ‘check’ button. Optionally, consequences on sub-step results can be visualized as well. As an alternative the parameters can be modified in the ASCII text parameter file (see §4.3), but without having the possibility to test the consequences directly.

During the development of BASEGRAIN several parameters have been tested, of which the most were found to be of minor importance. However, these parameters have been kept changeable. To distinguish more easily between decisive and less important parameters, the request fields of the former are highlighted in light red. Their effects are handled in detail below.

Decisive parameters in step #1 are the size of the median filter that is applied to the initial gray scale image, *medfiltsiz10* [px], the multiplier to Otsu’s (1979) gray-thresh value that determines definite interstices, *facgrayhr1* [-], and alike *facgrayhr2* [-] estimating possible interstices by (*facgrayhr1* + *facgrayhr2*) as multiplier to Otsu’s gray-thresh value; furthermore the size of the block in which Otsu’s gray-tresh value is determined, *blocSizG* [px], and finally the multiplier *mfG* [-] to *blocSizG* that defines the median filter to smoothen the resulting gray-tresh raster. Figure 2 shows an example on how these parameters affect the interstice detection. As a rule of thumb *medfiltsiz10* and *facgrayhr1* should be adjusted so that no intra-granular noise becomes prominent.

In step #2 decisive parameters are the size of the median filter that is applied to the initial gray scale image, *medfiltsiz20* [px], and the criteria *criteriCutL2* [-]. The latter gives the minimal percentage up to that possible areas of interstices gained by bottom-hat filtering have to be congruent to definite interstices fixed in step #1. Figure 3 shows an example on how these parameters affect the interstice detection. As a rule of thumb appendices of possible interstices should not reach too far into grains areas. The adjustment

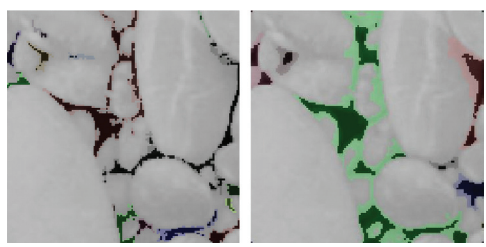

Figure 2. Effect of adjusting the analysis parameters of step #1 of object detection methodology. Left: [*medfiltsiz10, facgrayhr1, facgrayhr2, blocSizG, mfG*] = [1 px, 0.8, 0.1, 8 px, 1], right: = [3 px, 0.7, 0.2, 32 px, 2]. Dark colored interstices indicate definite interstices, whereas light colored interstices indicate possible interstices, resp. Here, the parameters to obtain the right figure were finally chosen best, as they provide a less noisy result within half calculation time than needed for left.

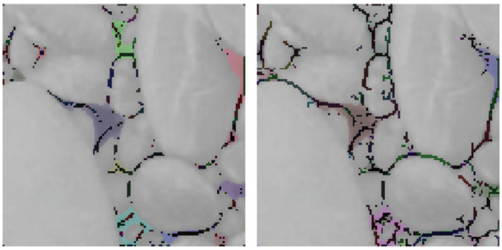

Figure 3. Effect of adjusting analysis parameters of step #2 of object detection methodology. Left: [*medfiltsiz20*, *criteriCutL2*] = [3 px, 0.9], right: = [1 px, 0.1]. Here, parameters of the right plot were finally chosen best, as they provide a more precise definition of interstice areas than on the left.

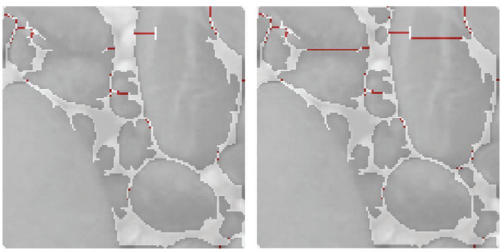

Figure 4. Effect of adjusting analysis parameters of step #4. Left: [*areaCutLfA*, *areaCutWW*] = [100, 20] px, right: = [50, 40] px. Here, parameters of right figure were finally chosen best, as they suppress over-segmentation adequately.

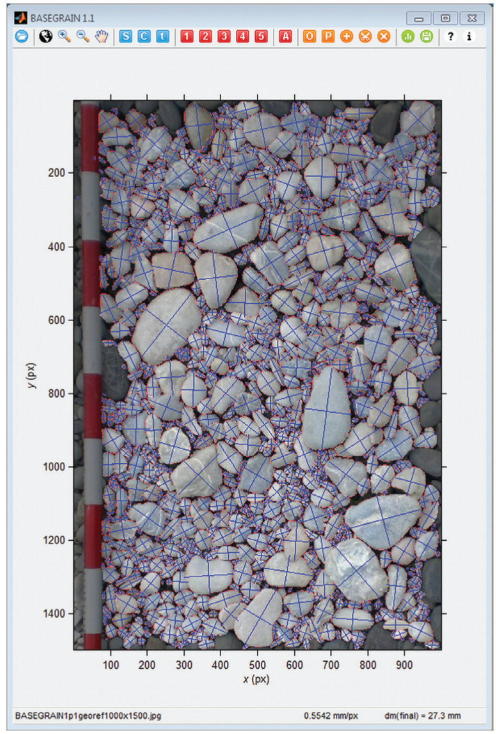

Figure 5. Final result of automatic object detection procedure. Straight lines (color print: blue) represent *a*-axis and *b*-axis of ellipses fitted to each object using normalized second central moments of determined object areas. Pixels of grain boundaries are highlighted (color print: red). Grains with contact to enclosing frame are blanked out. First estimation of fractional weighted mean diameter d_m is given at baseline information bar.

of the parameters used in step #3 is of minor importance to the final result so that it is recommended to use the default values.

Decisive parameters in step #4 are the minimal size of a grain area, *areaCutLfA* [px], to which the watershed algorithm is applied, and the minimal allowed length of a watershed bridge *areaCutWW* [px]. Figure 4 depicts exemplarily how these parameters affect the interstice detection. It is recommended to use *areaCutLfA* = 25–100 px and *areaCutLfA* = 0–100 px, depending on the intragranular noise of the inspected gravel bed.

Solely one parameter in step #5 is of importance to the final result: The parameter *smallestArea* [px] defines the minimal number of pixel needed to confirm a detected area to be a real grain area. According to Graham et al. (2005b) the value is ≥23 px.

4.7 *Automatic object detection*

The five-step automatic object detection is started by pressing the red 'A' button (shortcut key 'a'). Mainly depending on the number of grain areas separating the detection process lasts between a few seconds up to one minute. A crude estimation is made by a bulk detection velocity of 100 objects/s (corresponding to BASEGRAIN 1.1 with a 2.80 GHz processor on a 64 bit system). Once the object detection process is finished, the result is visualized on the working surface. Figure 5 shows a typical screenshot at this state.

4.8 *Post-processing*

With finishing the object detection process successfully, the five orange post-processing buttons as well as the green buttons for analysis and data export are enabled.

By alternately pressing the 'objects view' button (shortcut key 'o') and the 'photo view' button (shortcut key 'p') the user can switch between these two views to cross-check the results—optionally supported by the zoom and pan functions.

If the ‘merge objects’ button (shortcut key ‘m’) is clicked, over-segmented grains are unified. Single left mouse clicks on wrongly separated pieces of a grain define their connectivity, and a right mouse click (alternative: a fast double left mouse click) finishes the subscript operation for the actual grain. Then, a different grain area can be handled in the same manner. A final right mouse click (alternative: a final fast double left mouse click) ends the merge-indexing for all grains. Finally, each grain area gets merged as defined by the user.

If the ‘depart objects’ button (shortcut key ‘d’) is clicked, under-segmented grains are separated. Single left mouse clicks define an artificial interstice polyline, and a right mouse click (alternative: a fast double left mouse click) finishes the subscript operation of the actual polyline. Then, a next artificial interstice polyline can be generated in the same way. A final right mouse click (alternative: a final fast double left mouse click) ends the polyline-indexing for under-segmented grain. The whole area to be re-analyzed is recalculated, starting at step #4 with all fixed and possible interstices considered up to this level. Note that the ‘depart objects’ function also can be used to blank in grains by setting artificial interstices.

If the ‘blank out objects’ button (shortcut key ‘b’) is clicked, falsified areas are removed. Single left mouse clicks define the areas to be blanked out, and a right mouse click (alternative: a fast double left mouse click) finishes the operation script. Each area clicked at least once gets now defined as interstice area. Figure 6 illustrates an example on how the inactive object handling within the post-processing affects the final result of the detected object areas.

4.9 *Analysis*

Grain size distributions can be determined by the analysis menu. It is accessed by pressing the ‘result analysis’ button (shortcut key ‘r’). A new window pops up, where single analysis parameters can be changed optionally. Effects on the grain size distribution are studied by pressing the ‘check’ button. Then, Fehr’s (1987) line-sampling method is applied to the detected grain areas, where the lines are spanned vertically and horizontally. Per default their distance is 50 px. Figure 7 shows a typical result in comparison with results from laboratory sieving, with a quite good overall agreement.

The user has the possibility to choose between four different types of analysis graphs when pressing the ‘check’ button. These results are describes next.

If the radio button ‘fig60.14’ is switched on, the graph gives the quasi-sieve throughput q_i [-], based on the top-view b-axis by number. Here, the analyzed grain classes are defined by the given classes of the in-situ line sampling data *LbN01.data*.

If the radio button ‘fig60.15’ is switched on, the graph gives the quasi-sieve throughput p_i [-], based on the top-view b-axis by volume according to Fehr’s (1987) methodology. Here, the analyzed grain classes are defined by the given classes of the in-situ line sampling data *LbN01.data*.

If the radio buttons ‘fig60.16’ or ‘fig60.20’ are switched on, the graph again gives the quasi-sieve throughput p_i [-]. However, now analyzed grain classes are defined by the given classes of the laboratory sieving data *StV01.data*. For ‘fig60.16’ a comparison is given to *LbN01.data* and *StV01.data*, whereas ‘fig60.20’ compares solely the *StV01.data*, yet the full methodology of Fehr (1987) is applied, in which the lack of the non-detected fines is approached via a Fuller curve estimation.

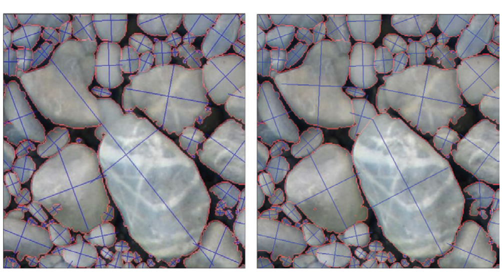

Figure 6. Effect of interactive post-processing on precision of object detection procedure. Left: before post-processing, right: after post-processing.

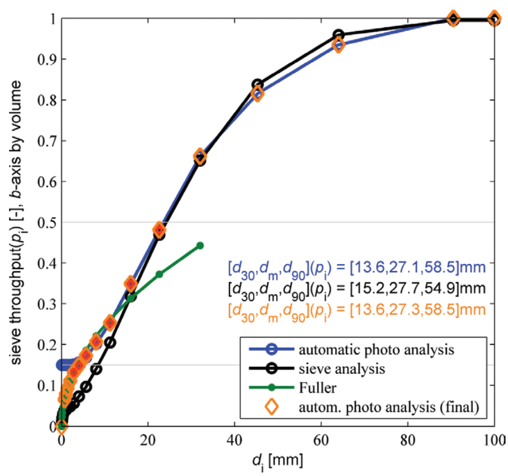

Figure 7. Grading curve for subsurface material resulting from automatic photo analysis of image given in Figure 5, in comparison with results from common laboratory sieving gained at same location.

Decisive parameters to transfer the results from the gravel surface into subsurface grain size distribution are Fehr's (1987) exponent *alpha1* and the pre-estimation of the percentage of non-detected fines *corrfine1*, respectively. Reference data from in-situ line sampling and laboratory sieving can be added as well via the 'result analysis' menu. Alternatively the parameters can be modified in the ASCII text parameter file (see §4.3), but without having the possibility to cross check them instantly.

4.10 *Data export*

Control parameters and analysis reports can be exported to common file formats. The menu is started by clicking the 'export data'-button (shortcut key 'e').

The control parameter file saves all actual parameter settings as ASCII text file written in MATLAB-editor language. Note that information on 'merge objects', 'depart objects' and 'blank out objects' is saved as well—if these options have been used before. During an import of the actual control parameter file within a forthcoming new session, the automatic object detection will perform each time as follows: (1) 'merge objects', (2) 'depart objects' and (3) 'blank out objects', independent of the sequential arrangement of the original session. Results can be saved as EXCEL spreadsheets file if this software is installed on the computer. The exported data contents are grain-size curves, grain size statistics, all known properties on each detected grain, and further data including the total void area and the non-boundary grain area, amongst others. The whole actual data set can be saved as binary MATLAB data file (mat-file).

If geo-tagged photographs are analyzed, or if the WGS84 coordinates are known, analysis reports can be exported to common GIS-file formats, i.e. kml-file (Google Earth) and shp-file (ESRI). Figure 8 shows an example where the properties of a geo-referenced analysis are displayed.

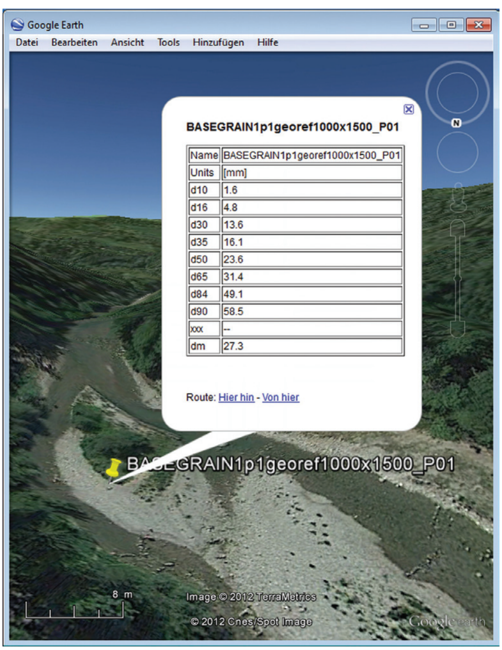

Figure 8. Google Earth snapshot in which BASEGRAIN results are displayed.

4.11 *Further functions*

The 'help online' button (shortcut 'h') launches the default web-browser and directly links the user to the BASEGRAIN homepage. The 'info' button (shortcut 'i') opens a small window with information on the currently used version of BASEGRAIN. In case BASEGRAIN crashes, take advantage of the 'escape' button to set all variables back to default values.

5 SUMMARY AND OUTLOOK

BASEGRAIN is a free software-tool with graphical user interface that enables gravelometric analysis of non-cohesive river beds. It calculates the grain size distribution of the surface layer and gives an estimate to the subsurface layer, respectively. The procedure is non-intrusive. The core of the methodology involves MATLAB-based object detection techniques applied to analyze digital top-view photographs of gravel layer surfaces. If geo-tagged photographs are analyzed, georeferencing is done automatically. Analysis reports can be exported to common file formats.

BASEGRAIN detects individual surface particles as precise as traditional field methods. We expect that BASEGRAIN will soon become a widely used tool in the field of gravel-bed analysis. The time effort for a grain size analysis by automatic object detection is only at a fraction of the time needed for classical methods. A further benefit is that additional parameters can be determined for each grain such as: ratio of minor axis/major axis, area, perimeter, center coordinates, and the grain orientation in a horizontal plane. Consequently, automatic object detection methodologies as implemented in BASEGRAIN should become widely-used in the field of gravel-bed analysis.

Graham et al. (2010) and Strom et al. (2010), respectively, have developed similar image based approaches to characterize a grain size distribution. They demonstrated that their methods of automatic detection of individual surface particles are as precise as traditional field methods. As BASEGRAIN exceeds their accuracy, its applicability is implicated—at least for the analysis of surface material.

A systematic analysis concerning the reliability of the present method, its limits of application, as well as a comparison to surface and subsurface layer data from extensive field data and laboratory sieving, is currently in preparation. We are looking forward to the feedback of new users, and to receive additional calibration data that can help to further improve BASEGRAIN to the users' needs.

ACKNOWLEDGEMENTS

The part-support by the Federal Office for the Environment (FOEN, Switzerland, 'Fluvial monitoring of the new Flaz River') and by the Federal Institute of Waterways (BAW, Germany, 'Expert monitoring and analysis of subaqueous digital images of river beds') are gratefully acknowledged.

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